CHAPTER 6

Foresight, Punishment, and Cooperation

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Abstract

Understanding the evolution of social behaviors, norms, and institutions, which are at the core of all human cultures, requires understanding human decision-making processes. Two important characteristics of humans are that people care about future payoffs and that they have the "theory of mind" which allows them to predict to a certain extent the reaction of their social partners to their own actions. In evolutionary game theory, these characteristics can be modeled by a recently introduced strategy update method called foresight. This chapter discusses applications of foresight to several evolutionary games describing the effects of punishment on cooperation in repeated dyadic or group interactions. It is argued that foresight is able to solve both the first and second order free-rider problems, simplifying cooperation and the evolution of social institutions. Moreover, it can maintain social norms. Foresight can also undermine cooperation by allowing for manipulation and tactical deception.

Key Words: cooperation, conflict, punishment, evolutionary game theory, social norm, manipulation, strategy revision

I. INTRODUCTION

In my research, I use mathematical models to study complex evolutionary processes.* The earlier part of my career was spent attempting to shed theoretical light on various puzzles in the field of evolutionary biology. Although most of my models were not specifically designed for understanding humans or their psychology but rather focused on general evolutionary processes, some of my

* The editors asked me to start by outlining the development of my research program.

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results would also apply to humans. I have worked on models of phenotypic plasticity and genotype–environment interaction, the dynamics and maintenance of genetic variation in multiple loci, fitness landscapes, coevolution and adaptation, sexual selection and sexual conflict, homosexuality, multicellularity, and some other related topics. A significant proportion of these efforts has focused on developing a mathematical theory of the origins and evolution of biodiversity via the process of speciation which Darwin (2003/1859) called a "mystery of mysteries." That work led to a monograph entitled *Fitness Landscapes and the Origin of Species* (Gavrilets, 2004), which represented an attempt to, first, formalize the arguments of evolutionary biologists of the 20th century on how new species arise and, second, provide additional theoretical insights into these processes. (The term *theoretical work* may mean different things in different disciplines. Here, by *theoretical work*, I will mostly mean mathematical modeling.)

A. Why Models?

Complex evolutionary processes such as speciation are affected by many different forces (genetic, ecological, developmental, environmental, etc.) interacting in nonlinear ways. Both this complexity and the difficulties of experimental approaches, coming in particular from the very long timescales that are typically involved, imply that mathematical models have to play a very important role in evolutionary research. The abilities of models to offer insights into the complex processes, to develop or strengthen our intuition, to provide a general framework for synthesizing accumulated knowledge and generating hypotheses to test, and to identify key components as well as relevant spatial scales and timescales in their dynamics are invaluable. Therefore, it is not a surprise that developing mathematical models and testing their predictions empirically have played a central role in evolutionary biology research for 100 years now, starting with the work of Fisher, Haldane, and Wright (Provine, 1971, 1986).

The common wisdom is that a picture is worth a thousand words. In the exact sciences, an equation can be worth a thousand pictures. Equations, their predictions, and interpretations are the most concrete results a theoretician can come up with. Some say that the maturity of a science correlates with the degree of its mathematical sophistication. From this point of view, evolutionary biology as well as population ecology (where mathematical modeling was pioneered by Lotka and Volterra in the 1920s) and epidemiology (where modeling started with Roos and Kermack and McKendrick in the 1910s–1920s) are indeed mature sciences. The application of mathematical modeling in social sciences in general and for studies of cultural evolution in particular has a shorter history, but it is growing steadily. It goes without saying that mathematical models must be based on solid empirical foundations and that close collaboration of empiricists and theoreticians is crucial for scientific progress in any area.

B. Human Origins

Turning back to the development of my research program, after completion of my book, I came to realize that the time was ripe for attacking the ultimate speciation event—the origin of our own species (Darwin, 1871). Human origins and our subsequent cultural and social evolution should be explainable using the logic of general evolutionary processes, and many of the tools, methods, ideas and models developed by empirical and theoretical evolutionary biologists should be useful for understanding human behavior and psychology. Nevertheless, it was apparent to me that the puzzle of human origins and distinctiveness needed much more empirical and theoretical work. It also became clear to me that research on human origins and our subsequent cultural and social evolution was vital for understanding, mitigating, and solving some of the most pressing challenges faced by our society (Gavrilets et al., 2021). For example, humans strongly react to inequality and injustice, a behavior that we share with other primates (Brosnan & de Waal, 2014). Understanding the evolution of our sense of fairness may help us build a more just society. Similarly, studies of sexual selection as well as genetic and cultural diversity can shed light on gender-, race-, and ethnicity-related prejudices; their consequences for human behavior; and ways to mitigate undesirable effects. Insights into the factors shaping human (pro)sociality can be leveraged to improve the efficiency and benevolence of collective actions in businesses and communities. They can foster more efficient economic, political, social, and educational policies. Such insights can also be applied to better understanding of motivations leading to the onset and maintenance of both violent and non-violent conflicts, which can increase societal resilience to external and internal shocks. Our long-term persistence requires addressing existential risks from climate change, biodiversity loss, depletion of non-renewable resources, and security threats posed by unstable political systems. Humans have evolved various psychological mechanisms and biases for making collective decisions which need to be considered when developing policies for sustainability (Brooks et al., 2018).

C. Human Distinctiveness

One factor that influenced and motivated me greatly initially was the discussion of human uniqueness (and its origins) in the writings of Richard Alexander (1987, 1989, 1990) and others (Flinn et al., 2005). There were a number of evolutionary puzzles related to this yet to be solved. For example, how can we use evolutionary theory to explain and model the evolution of human cognition, of pair-bonding, of our sense of fairness, of coalition formation? I began working on these topics (Bissonette et al., 2015; Gavrilets, 2008, 2012a, 2012b; Gavrilets & Vose 2006; Mesterton-Gibbons et al., 2011). I also started collaborations with primatologists and anthropologists whose domains of research interest are positioned, in a sense, on the opposite side of the major evolutionary transition I was interested in. Later I came to understand, mostly through my interactions with Frans de Waal, that it probably makes much more sense to talk about "human distinctiveness" rather than "human uniqueness" as most differences between humans and "the higher animals, great as [they are], certainly [are ones] of degree and not of kind," as clearly stated by Darwin (1871, p. 85) himself. I note that the 150th anniversary of Darwin's *The Descent of Man* offered scientists a unique opportunity to advance the appreciation of science in general, of life and the social sciences in particular, and of a diversity of topics related to human origins and evolution (Gavrilets et al., 2020).

D. Cooperation and Conflict

As often happens in one's scientific career, my interests expanded into "adjacent" research areas, and I became interested in the processes happening in historical and contemporary humans and their societies. I started discussions and collaborations with psychologists, sociologists, economists, political scientists, and cultural evolutionists. In particular, through my collaboration with Peter Turchin and Peter Richerson, I got deeply involved in the issues of the evolution of human social complexity, cultural evolution, as well as cooperation and conflict in human groups and societies.

Cooperation can potentially be very profitable for all parties involved because cooperating groups can acquire material benefits that would be completely out of reach (or too costly) for single individuals (Smith, 1776/2008). To realize this potential, however, group members have to be able to overcome certain hurdles: They have to effectively coordinate their actions, resolve potential conflicts, and eliminate or minimize free-riding. The collective action problem (i.e., free-riding of group members) is generic for both human and non-human animal groups and can easily undermine within-group cooperation (Hardin, 1982; Olson, 1965; Pecorino, 2015; Sandler, 1992). Collective action problems can be (partially) resolved by several mechanisms including kin cooperating with each other, direct reciprocity (when individuals directly exchange favors), indirect reciprocity (when individuals cooperate with others who have reputation of being cooperative), punishment, group selection (when certain individually costly behaviors increase group survival), selective incentives (when cooperators are rewarded by the group), within-group heterogeneity (when certain individuals benefit from a collective action more than others), leadership, as well as social norms and social institutions regulating individual and group behavior (Bowles & Gintis, 2011; Gavrilets, 2015; McElreath & Boyd, 2007; Nowak, 2006; Olson, 1965; Richerson & Boyd 2005).

A significant effort has been devoted to theoretical and experimental studies of the effects of punishment of free-riders on cooperation (Boyd & Richerson, 1992; Boyd et al., 2003; Fehr & Fischbacher 2004; Fehr & Gächter, 2002; Heckathorn, 1989; Panchanathan & Boyd, 2004). Initially it appeared that punishment was a very powerful way to enforce cooperation and solve the collective action problem (Boyd & Richerson, 1992). However, it was quickly realized that if punishing others is costly, the act of punishment itself becomes a collective good which leads to a second-order free-rider problem as one would prefer others to administer costly punishment. Subsequently, theoreticians devoted a lot of their efforts to solving this second-order free-rider problem. The proposed solutions include meta-punishment (when there is a social norm requiring punishment of individuals who violate social norms), conformism, signaling (when individuals punish others to increase their own reputation), and group selection (Andreoni, 1988; Boyd et al., 2003; Gilby et al., 2015; McElreath & Boyd, 2007; McGinty & Milam, 2013; Olson, 1965; Ostrom, 2000; Panchanathan & Boyd, 2004).

But, from my own real-life experience, it was obvious that something important was missing in these theories. Indeed, when a child does something bad, most parents would discipline them. Naturally, it is never a pleasant experience, but parents would do it with a specific, bigger goal in mind—to modify the child's future behavior. So a parent would expect that the immediate cost of disciplining a child would, in a sense, be compensated by future benefits to both the parents and the child. Naturally, similar reasoning applies to many other situations and social interactions.

E. Foresight

These intuitions led me to propose a particular mechanism (and a corresponding mathematical model) for decision-making regarding punishment that can solve collective action problems. I called it *foresight*. Foresight is based on two postulates: First, individuals care about future payoffs and, second, they are able to predict to a certain extent the reaction of their social partners to their own actions. These "postulates" are not just based on common knowledge but are also well established in the scientific literature, and strong empirical evidence supporting them is in plain sight.

Indeed, humans have the ability to represent mentally what might happen in the future (captured in the notion of prospection [Szpunar et al., 2014]) and are routinely engaged in making intertemporal choices when they have to trade off costs and benefits at different points in time (Berns et al., 2007; Frederick et al., 2002). Intertemporal choices imply self-control (Hayden, 2019), which is also found in other animals (MacLean et al., 2014; Miller et al., 2019). Consideration of future payoffs is also explicit in many game-theoretic models, where it often comes under the rubric of the "shadow of the future" (Axelrod, 1984). The latter essentially is the idea that people behave differently when they expect to interact with someone repeatedly over time. For example, consider a classical repeated prisoner's dilemma game where an individual can provide benefit b to the partner at the cost c to themselves. Let w be the probability of another encounter between the same two individuals so that they will play on average $1/(1 - w)$ rounds. Then consideration of expected payoffs over $1/(1 - w)$ rounds shows that the tit-for-tat strategy is an evolutionarily stable strategy if probability w exceeds the cost-to-benefit ratio c/b of the altruistic act (Nowak, 2006). Another example of consideration of future payoffs in game theory is the backward induction principle (von Neumann & Morgenstern, 1944), which is an iterative process of reasoning backward in time used to study sequential games in which players make moves in a particular order.

In a similar way, the ability to mentally construct possible events in the future, travel mentally in time, and build mentally various scenarios plays an important role in discussions of human distinctiveness, consciousness, intelligence, and shared intentionality in the psychological literature (Alexander, 1987; Call, 2009; Suddendorf & Corballis, 1997; Tomasello et al., 2005). In particular, it is well accepted that this ability has evolved because it contributes to the future survival of individuals and groups through processes of social competition and/or cooperation (Alexander, 1989; Suddendorf & Corballis, 1997; Tomasello et al., 2005). More recent work draws attention to these abilities as a factor in the evolution of cumulative culture (Vale et al., 2012) and the evolution of effective learning strategies (Fogarty et al., 2012). The understanding that others will change their actions in response to one's own actions is a consequence of humans' *theory of mind*—the ability to reason about the knowledge and thought processes of others. The theory of mind is a well-established trait in humans (Premack & Woodruff, 1978; Tomasello et al., 2005), and it is thought to be key in promoting cooperation within groups (Tomasello et al., 2005). Humans can use the theory of mind recursively (Hedden & Zhang, 2002; Perner & Wimmer, 1985), which implies thinking about how others think about you.

It should also be obvious that similar considerations and forces also work in many non-human animals. For example, a subordinate male in a group of chimpanzees will rarely attempt to take food or a mating opportunity from a dominant individual because punishment will likely be immediate and severe. The existence of the theory of mind has been demonstrated experimentally in apes (Call & Tomasello, 2008; Kano et al., 2019; Krupenye et al., 2016). A more general set of examples are common cases of manipulation and tactical deception in animals, which are thought to have evolved as an evolutionary response to mind-reading (Hall & Brosnan, 2016; Krebs & Dawkins, 1984).

Theoretical and experimental studies of cooperation and punishment provide further evidence for foresight. For example, in his highly cited paper "An Evolutionary Approach to Norms," Axelrod (1986) gives an extensive discussion of eight different mechanisms that can support cooperative behavior. His Mechanism 4 was called *deterrence*. Its logic was straightforward: "players may have a great enough understanding of the situation to do some forward-looking calculations. . . . In particular, a person may realize that even if punishing a defection is costly now, it might have long-term gains by discouraging other defections later" (p. 1104). Fehr and Gächter (2002), in their classical experimental study of the effect of punishment on cooperation in a public goods game, observed that "the punishment threat was immediately effective" (p. 138), as was evident by the big increase in investments (see Figure 6.1) when the punishment opportunity was introduced, that is, even before any actual punishment took place. Krasnow et al. (2012) studied a two-round trust game with punishment. They observed that "subjects direct[ed] their cooperative efforts preferentially towards defectors they have punished and away from those they haven't punished" and "subjects were just as likely to

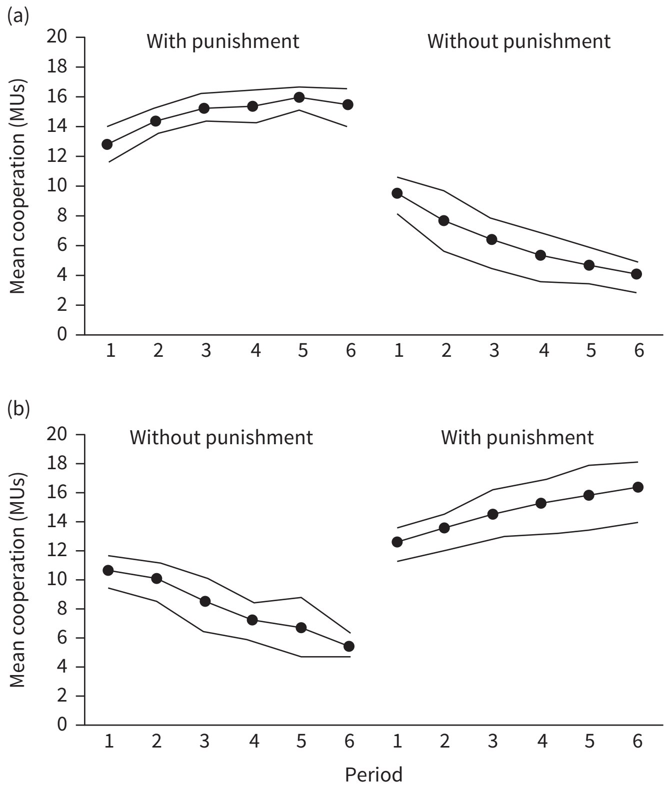

FIGURE 6.1: Time trend of mean group contributions in a public goods game together with the 95% confidence interval. (a) During the first six periods, subjects have the opportunity to punish the other group members. Afterward, the punishment opportunity is removed. (b) During the first six periods, punishment of other group members is ruled out. Afterward, punishment is possible. MU are money units used.
Source: Fehr & Gächter (2002, Figure 2) (reproduced with permission).

cooperate in round two with a defector whom they had punished in round 1 as with a partner who had cooperated in round 1." That is, individuals expected that the punishment they administered earlier was effective in modifying the target's behavior. (I note that punishment can, of course, have other purposes besides deterrence [Carlsmith, 2008; Carlsmith et al., 2002; Cushman, 2015], which I do not consider here.)

My final example is rather broad and general. It concerns social norms which are central to human behavior. (As Tomasello [2011, p. 20] puts it, "Humans live in a sea of social norms that govern pretty much all aspects of their lives.") There are different types of social norms (Bicchieri, 2006; Ensminger & Henrich, 2014; Grusec & Kuczynski; 1997; Lapinski & Rimal, 2005). For example, descriptive norms involve perceptions of which behaviors are typically performed and what people actually do. In contrast, injunctive social norms are behaviors that one is expected to follow and expects others to follow in a given social situation. That is, they refer to what people ought to do. One of the reasons people follow injunctive social norms (and as a consequence often behave in a way that reduces their immediate material well-being) is because they are afraid of being punished and/or disapproved of as a result of norm violation. That is, people know that if they go after an immediate material benefit by violating a social norm, their action may trigger punishment or disapproval by others. Often, such foresight is sufficient to prevent a norm-violating behavior.

To reiterate, the fact that people care about the future and are able to foresee to a certain extent the reaction of their social partners to their action is well established. However, these facts and ideas have so far not been incorporated in theoretical models. In the following section, I first outline how I define foresight mathematically. Then I discuss applications of foresight to several evolutionary games, describing the effects of punishment on cooperation in repeated dyadic or group interactions. I argue that foresight is able to solve both the first- and second-order free-rider problems, simplifying cooperation and the evolution of social institutions. Moreover, it can maintain social norms. Foresight can also undermine cooperation by allowing for manipulation and tactical deception.

II. THEORETICAL FRAMEWORK AND MAJOR CONCEPTS

Game theory is the most appropriate theoretical tool for studying strategic interactions between multiple individuals (Binmore, 1990; Fudenberg & Tirole, 1992; von Neumann & Morgenstern, 1944). In classical game theory, a game-theoretic model has three main components: players, their possible actions ("strategies"), and the "payoffs" that each player gets after each possible social interaction. In classical game theory, players have complete information about the game, are fully rational, and can identify most beneficial strategies. Then one can, at least in principle, find certain states (Nash equilibria) that no player would want to deviate from once this state is reached, the expectation being that these states will somehow be realized.

Three relatively recent extensions of classical game theory have played an important role in my work on foresight: strategy update methods, utility functions combining material and normative costs and benefits, and methods for modeling errors in the decision-making process.

A. Strategy Revision Method

The assumptions of classical game theory about unbounded knowledge and rationality are very strong and clearly unrealistic. Evolutionary game theory is an extension of the classical theory, which does not rely on these assumptions. Instead, evolutionary game theory brings an additional component to each model—a strategy update method which specifies how players change their strategies from one interaction to another. Then, as players go through multiple rounds of interactions and strategy updates, the distribution of strategies in the population evolves through time, potentially converging to a certain attractor (e.g., a Nash equilibrium).

In the original formulation (Maynard Smith, 1982; Maynard Smith & Price, 1973), which was inspired by population genetic models in evolutionary biology, the players are genetically hardwired to always play a particular strategy. At the individual level, their strategy changes only as a result of a random mutation (usually at birth). At the population level, the changes in the distribution of strategies happen as a result of differential birth and death rates, with players with high-payoff strategies leaving more surviving offspring than players utilizing low-payoff strategies. Under this approach, the details of the strategy update method (i.e., mutation rate) play a secondary role in evolutionary dynamics, with mutation merely supplying the necessary variation while the population evolution is mostly driven by differences in payoff (which is interpreted as biological fitness).

Later research has, however, brought in a number of additional and more realistic strategy update methods to the forefront of evolutionary game theory. These include individual learning, selective imitation (e.g., payoff-biased), myopic best response, and level-k modeling (Hofbauer & Sigmund, 1998; Sandholm, 2010). Rather than assuming that individuals are hardwired to behave in a particular way, these methods grant some free will and bound rationality to the players. For example, individuals using best response attempt to answer the question, What is my best option given the current strategies of all of my social partners? Individuals using level-1 modeling (which is a special case of level-k modeling) attempt to answer the question, What is my best option given my social partners choose strategies randomly? Likewise, individuals using selective payoff–biased imitations try to identify a player with the highest payoff among their social partners and copy the corresponding strategy. From a formal modeling point of view, foresight is a new strategy update method allowing for bounded rationality of players.

In evolutionary biology, mutation is viewed as random and consequently does not play a creative or large role in evolutionary processes (although mutation biases do exist and can be important under some conditions). In contrast, in modern developments of evolutionary game theory, selection can happen at the level of new strategy generation (Sandholm, 2010), for example, when agents evaluate different possible strategies mentally with respect to expected payoffs. As a result, changing a strategy update method, while keeping all other components of a game-theoretic model the same, can strikingly change the resulting evolutionary dynamics.

Consider, for example, a classical model in evolutionary game theory in which individuals are randomly paired to play the standard rock–scissors–paper game (e.g., Hofbauer & Sigmund, 1998). There are three strategies such that rock beats scissors, scissors beats paper, and paper beats rock. Players are motivated to increase their payoffs. They change their strategies according to a particular strategy revision protocol, for example, by choosing a best response to the previous game of the opponent (best response protocol) or by choosing a strategy that had overall the highest payoff in the previous round (replicator dynamics protocol). The state of the population can be characterized by the frequencies of the three strategies which can be visualized as a point on an equilateral triangle, while evolutionary dynamics can be described by a curve (trajectory) on this triangle (as in Figure 6.2). In this game, there is an equilibrium at which all three strategies are present at equal frequencies. This equilibrium exists under all standard strategy revision protocols. However, whether this equilibrium is approached asymptotically and the pattern and speed of convergence vary dramatically between different strategy revision protocols (see Figure 6.2).

One consequence of this is that, while the first- and second-order free-rider problems exist independently of the strategy update method, people's decision-making process can greatly affect the ability of groups to overcome these problems. For example, selective payoff–biased imitation is not able to solve the first- or second-order free-rider problem without invoking additional mechanisms (e.g., group selection or reduced migration and inbreeding). In contrast, a group of individuals capable of foresight can overcome these problems.

B. Utility Function

Cultural evolutionists often express unhappiness with what they perceive as economists' focus on material payoffs and disregard of normative values in

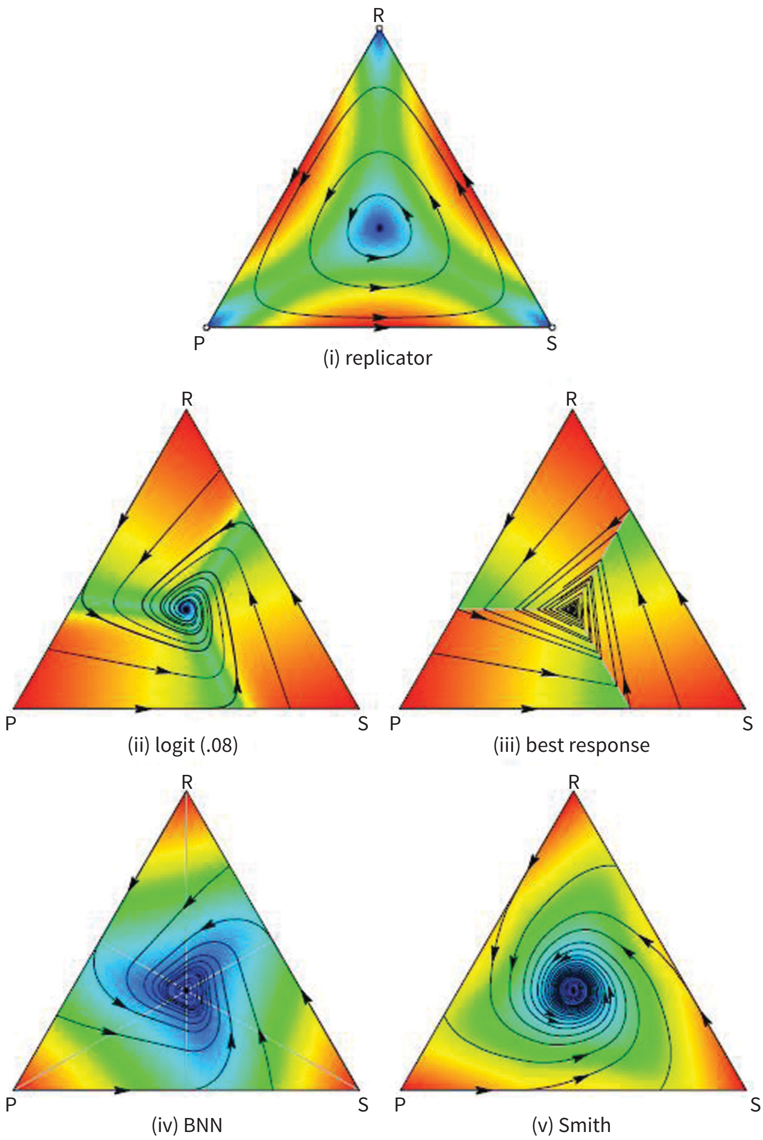

FIGURE 6.2: Strikingly different deterministic dynamics in standard rock–paper–scissors game under five different strategy update methods (labeled replicator, login, best response, Brown-von Neumann-Nash (BNN), and Smith). Colors represent speeds: Red is fastest; blue is slowest.
Source. Sandholm (2009, Figure 1).

the economists' models. I do not think this view is justified. Economists have developed a very powerful notion of utility function which can capture both material and immaterial/normative costs and benefits (e.g., Akerlof, 1980; Azar, 2004, 2008; Berhheim, 1994; Nyborg, 2018). For example, to mathematically capture the idea that changing an action/strategy x can have material consequences, for example, changing payoffs $\pi(x)$, as well as affect some normative values $v(x)$ for individuals, one can postulate that in making a decision on a possible action x, individuals attempt to maximize a utility function

$$u(x) = (1 - \eta)\pi(x) + \eta v(x)$$

where $0 \leq \eta \leq 1$ is a parameter measuring the importance of normative values relative to material payoffs (Gavrilets & Richerson, 2017). Note that if $\eta = 0$, individuals care only about material benefits: $u(x) = \pi(x)$. In contrast, if $\eta = 1$, individuals care only about normative values: $u(x) = v(x)$. (In the terminology of Wrong [1961], individuals with $\eta = 0$ are undersocialized, while individuals with $\eta = 1$ are oversocialized.)

C. Errors

It is natural to expect that when individuals attempt to find an action or strategy that maximizes their payoff (or utility), some errors are inevitable. It is also reasonable to assume that the error becomes more likely as the differences in payoffs/utilities between different options become small. A simple and powerful way to capture these intuitions is to assume that individuals chose a particular strategy x with probability proportional to its utility. For example, assuming logit errors, we can set this probability to $\exp(\lambda u[x])$, where $0 \leq \lambda \leq \infty$ is a non-negative precision parameter. If λ is very small, different actions will be chosen with similar probabilities; if λ is very large, the action with the highest utility u will be most definitely chosen. Using this stochastic approach leads to a powerful generalization of Nash equilibrium known as quantal response equilibrium (Goeree et al., 2016).

D. Modeling Foresight

Now we are in a position to introduce the strategy update method foresight formally. Assume that agents are engaged in repeated interactions happening at discrete moments in time. For example, the agents could be playing a two-stage game: a collective goods game, followed by peer punishment. After each such round, the agents are given an opportunity to update their strategy with probability ν. The agents may expect that if they chose a particular behavior for the next round, their social partners will likely react to this behavior by adjusting their own strategy accordingly in the subsequent round. We then postulate that the focal agent attempts to maximize a generalized utility function

$$U(x) = (1-\omega)u(x) + \omega u'(x) \tag{1}$$

which is a weighted sum of the expected utility at the next game $u(x)$ and the expected utility at the subsequent game $u'(x)$ (Perry et al., 2018). Parameter $0 \leq \omega \leq 1$ measures the importance of future payoffs. The case of $\omega = 0$ corresponds to myopic best response (i.e., no foresight). To evaluate utilities u and u', the focal agent needs to be able to predict how their social partner(s) will behave in the next and the subsequent rounds. This can be done, for example, by asking the question, What would I do in their place, or alternatively by assuming that social partners use a simple strategy update protocol, such as myopic best response. In the numerical implementations of foresight to be illustrated, the players mentally generate a number of "candidate strategies" x and then pick one of them with a probability proportional to $\exp(\lambda\, U[x])$, where λ represents the precision with which an agent estimates utilities.

Before I illustrate the applications of this method, several clarifications are in order. First, this approach is an example of bounded rationality (Gigerenzer & Selten, 2001). It can be viewed as a generalization of standard myopic best response for the case of individuals with a bounded ability to anticipate the actions of their group-mates and care about future payoffs. At the same time, foresight is related to level-k modeling (Nagel, 1995; Stahl & Wilson, 1995) but with a different definition of level-0 play. In the standard approach, level-0 players choose their strategies randomly. In contrast, in our approach level-0 players do not change their strategy from the previous round. That makes best responders equivalent to level-1 players. This apparently small difference in the assumption about level-0 play actually turns out to be important (Perry & Gavrilets, 2020). The term *foresight* was used earlier in game-theoretic models considering expected future benefits but with a different meaning. In Jehiel (1995, 1998, 2001) and Heller (2015), players differed in their *foresight*, which was defined as the ability to predict after how many rounds from the current one a repeated prisoner's dilemma game will end. In their models, having longer foresight would result in a payoff advantage. In Mengel (2014), players formed beliefs about the behavior of their social partners by relying on past experience in the same situation and then using the best response to these beliefs over *t* periods ahead. Note also that earlier Blume (1995) showed that myopic best response arises whenever future payoff is discounted heavily or opportunities to revise a strategy arise sufficiently rarely. However, in all these models the players do not attempt to predict how their peers will adjust behavior in response to their actions. In contrast, the level-k models do attempt to capture the theory of mind. However, in level-k models players do not consider future payoffs or change their strategies/action depending on the behavior of their group-mates. The foresight in our implementation brings the ideas from these two approaches into the same modeling framework.

III. MAJOR PREDICTIONS AND EVIDENCE

The ideas and approaches outlined in this section were developed with my students and collaborators. I will start by introducing a model without foresight, which will serve as a reference point for illustrating the effects of foresight in other models to be considered subsequently.

A. Collective Action Problems in Heterogeneous Groups

Assume there is a population of individuals subdivided into a number of groups each of size *n* individuals. We consider two types of collective action (Gavrilets, 2015a). The first type focuses on group activities such as hunting and gathering, defense from predators, and building/maintaining shelter. The success of an individual group in these activities is largely unaffected by actions of neighboring groups. We refer to these actions as "us versus nature" games. In contrast, limited space, resources, and mating opportunities can result in direct competition between groups of individuals of the same species. This means that as the success of one group increases, the resources available to other groups decrease. We refer to such games as "us versus them."

1. *Efforts*. Assume that individual *i* in a focal group makes an effort x_i toward the group's success in a collective action. Effort x_i can be

treated as a binary variable (i.e., taking only two values: 0 and 1) or a non-negative continuous variable. Individual efforts of group members are aggregated into a group effort X. In the simplest case, the group effort is just the sum of individual efforts:

$$X = \sum_i x_i$$

2. *Probability of success in a collective action*. In the case of "us versus nature" games, I define the probability the focal group is successful as

$$P = X/(X + X_0)$$

where X_0 is a half-effort parameter (which specifies the group effort at which P = 50%). The larger X_0, the more group effort X is needed to secure the collective good. In the case of "us versus them" games, I define

$$P = X/X$$

where X is the average effort over all competing groups (including the focal one). Mathematically, in "us versus nature" actions, group members participate in a generalized public goods game which can also be viewed as a generalized volunteer's dilemma (Archetti, 2009; Diekmann, 1985). In "us versus them" actions, the groups compete in a contest (Konrad, 2009; Rusch & Gavrilets, 2020). The key distinction between these two types of collective action is that in the former the absolute group effort is critical for obtaining resources, while in the latter it is the group effort relative to that of the other competing group that matters.

3. *Payoffs*. Assume further that groups survive to the next generation with a probability proportional to their success in a collective action P. For individuals from surviving groups, the payoff (which is treated as biological fitness) is defined as

$$\pi_i = \pi_{0,i} + b\,v_i P - cx_i,$$

where $\pi_{0,i}$ is the baseline payoff, v_i is the share of the group reward going to individual i, and b and c are parameters measuring the benefit and cost of contributing to the collective action.

4. *Predictions*. Gavrilets and Fortunato (2014) and Gavrilets (2015a) studied this model assuming that individuals within each group were different with respect to their strength (which was assigned randomly according to a certain distribution). Individual strengths in turn controlled their shares/valuation v_i of the reward so that stronger individuals were getting a large share of the reward. The focus of modeling was on individual x_i and group X efforts and on relative individual shares of reproduction $f_i = \pi_i/\Sigma\,\pi_j$ observed at evolutionarily stable states. Note that variable f_i can be interpreted as relative fertility of individual i. Some of their results are illustrated in Figure 6.3. In general, individuals defect (i.e., choose $x = 0$) if they are "weak" so that their shares v_i of the rewards are small but cooperate (i.e., choose $x > 0$) if they are "strong" so that their shares v_i are large. This is what Olson (1965) called "the exploitation of the great by the small." In many cases, individual share of reproduction f_I grows with rank/valuation v_i.

However, under conditions of strong between-group competitions, the highest valuators (who are simultaneously the biggest contributors) end up with lower relative fertility f_I than other individuals because of the costs paid. This is the *altruistic bully effect* when strong and dominant individuals who grab the biggest share of the reward from their group-mate effectively become altruists in between-group conflicts, making the biggest effort and paying the largest costs. The reason for this apparent altruism is that the high-ranked individuals are effectively competing with their peers in other groups, and the most efficient way to do so is to increase their own efforts. Modeling results also show that increasing the reward size b causes an increase in the efforts of high valuators, but it can also decrease the efforts of low valuators who would increasingly free-ride. Allowing for group extinction results in two main effects. First, there are no free-riders anymore, and all group members contribute proportionally to their valuations. Second, individual and group efforts significantly increase. The effects of the group size n and the degree of inequality (characterized by the distribution of v_i values in the group) on the overall group effort X depend on the degree of non-linearity of various functions. That is, under some conditions, smaller groups can outperform larger

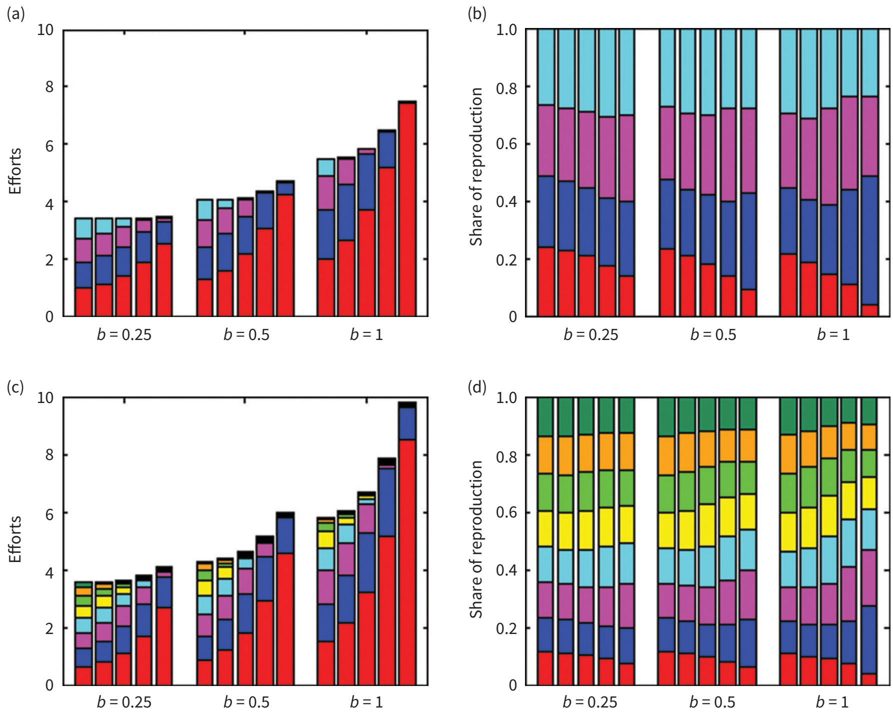

FIGURE 6.3: Collective action in the basic model. Summary results over with group size $n = 4$ (a, b) and $n = 8$ (c, d) individuals per group and cost c = 0.5. The values are averages over individuals of the same rank in all groups in the population. Colors show the relevant amounts for individuals of different ranks, from the highest-rank individual at the bottom (red) to the lowest-rank individual at the top. Each set of bars corresponds to a specific value of benefit *b*. Each bar within a set corresponds to a specific value of within-group inequality, from the smallest on the left to the largest on the right. (a) Individual efforts with group size $n = 4$; the height of the bar is the total group effort X. (b) Shares of reproduction for individuals of different rank with group size $n = 4$. (c) Individual efforts with group size $n = 8$; the height of the bar is the total group effort X. (d) Shares of reproduction for individuals of different rank with group size $n = 8$. Reproduced from Gavrilets & Fortunato (2014, Figure 4).

groups, while within-group inequality can have positive or negative effect on group effort.

B. Collective Action Problems in Heterogeneous Groups With Peer Punishment

In Perry et al. (2018), this model was generalized in several directions. First, we allowed for peer punishment. Specifically, besides deciding on the contribution

x_i to a collective action, each individual would choose a punishment threshold y_i and would consider punishing any group-mate whose contribution falls below y_i. We assumed that the cost inflicted by punishment was proportional to the difference between y_i and the contribution x_j of the group-mate. That is, we used a graduated punishment method (Gao et al., 2012; Helbing et al., 2010; Iwasa & Lee, 2013; Shimao & Nakamaru, 2013). The actual punishment happened only if the punisher was sufficiently strong relative to the target. Second, using agent-based simulations, we contrasted two strategy update methods: random mutation and best response. We allowed for three different types of group events happening with fixed probabilities: an "us versus nature" collective action, an "us versus them" contest against another randomly chosen group, and a "cultural group selection" event when members of one group would copy strategies of members of a higher-payoff group. In line with earlier work, we observed no cooperation or punishment in these models which was a result of the second-order free-rider problem. Consequently, our third step then was to introduce foresight.

Using the logic outlined before, we postulated that in making their decisions on the cooperative efforts x_i and punishment threshold y_i individuals attempt to maximize the weighted sum of the material payoffs of this and the next rounds (see Equation 1). The factors included in the model accounted for the benefits and costs of collective action as well as the costs of inflicted and received punishment. In making their decision, each actor would generate K pairs of candidate strategies (x', y') and would choose one of the them with probabilities proportional to the corresponding expected generalized utilities. To predict the actions of social partners, our agents assumed that their peers would best respond to their previous action.

Allowing for foresight immediately resulted in striking differences in behavior (see Figure 6.4). First, foresight allowed for the establishment of punishment, thus solving the second-degree free-rider problem. As a consequence, group efforts X in collective actions increased. Second, foresight resulted in the emergence of a division of labor in which more powerful individuals specialized in punishment, while less powerful individuals mostly contributed to the production of collective goods. Recall that without foresight we observed higher efforts and low payoffs of the strongest individuals (i.e., the *exploitation of the great by the small* effect and *altruistic bully* effects). With foresight, the situation has changed, and we observed the exploitation of the small by the great, where powerful individuals enjoyed higher payoffs than their group-mates. Interestingly, while foresight increases cooperation,

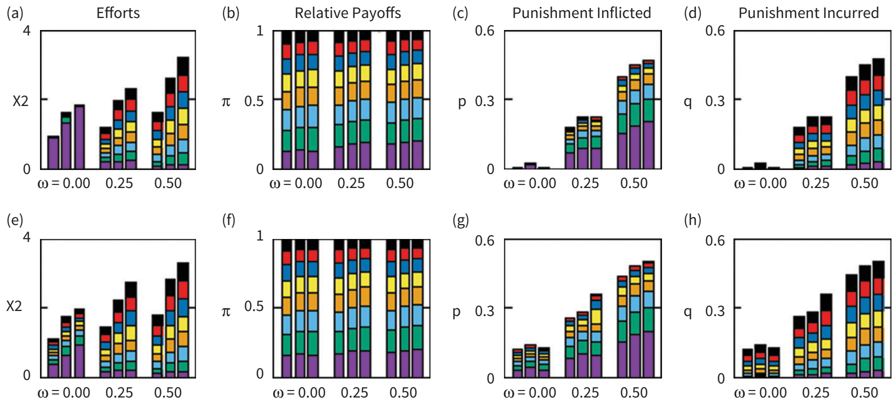

FIGURE 6.4: Effects of the foresight parameter ω on the group efforts X and relative payoffs π, the punishment inflicted p, and the punishment incurred q for individuals of different ranks in the full model with perfect (λ = ∞, first row) and imperfect (λ = 40, second row) precision. For each value of ω, the three bars correspond to groups mostly engaged in the "us versus nature" game (left bars), mostly "us versus them" games (right bars), and an equal frequencies of the two games (middle bars). The segments of each bar correspond to particular individuals, with the dominant at the bottom (purple) and the weakest at the top. Results are the averages of 20 simulations using: $n = 8$, $b = 1.0$, $c = 0.5$, β = 1, K = 2.
Reproduced from Perry et al. (2018, Figure 4).

it does not necessarily result in higher payoffs because much effort becomes wasted on punishment. We also observed that while between-group conflicts promoted within-group cooperation, as shown before, the effects of cultural group selection on cooperation were relatively small.

C. Evolution of Institutions

Our results on peer punishment can be interpreted as demonstrating evolutionary emergence on informal leadership, where strong individuals become leaders and weak individuals become followers. Our next step was to assume that such a division of labor is already established and collectively endorsed by group members, that is, that the punishment has become institutionalized. We wanted to look at its subsequent evolution in more detail.

The models that I will describe next belong to a class of models for the evolution of social institutions. Institutions that regulate social life are ubiquitous and are viewed as a key feature enabling the success of our species (Alesina & Giuliano, 2015; North, 1990; Powers et al., 2016; Richerson & Boyd, 2005; Singh et al., 2017). A question of particular theoretical and practical importance is how social institutions for collective action become effective and stable.

One powerful method of optimizing individual behavior is random innovation coupled with payoff-biased social learning when individuals observe and evaluate actions and payoffs of others and adapt strategies resulting in a higher payoff. Selective imitation can also drive cultural group selection, resulting in the spread of beneficial institutions across different groups (Richerson et al., 2016; Richerson & Boyd, 2005; Turchin, 2016). It has been argued recently that cultural group selection is the most important (or even the only) mechanism that can account for institutionalized cooperation in human societies (Chudek at al., 2013; Richerson et al., 2016; Turchin, 2016). However, there are questions about the power and usefulness of selective imitation within the context of collective action. At the level of individuals, because free-riders have higher payoffs than cooperators, their strategies are more likely to be imitated, which would undermine cooperation (Burton-Chellew et al., 2017; Molleman et al., 2014; van den Berg et al., 2015). Additionally, because of between-individual variation, a strategy that is good for one will not necessarily be beneficial or even feasible for another. At the level of groups, copying of institutions requires information flow between (potentially competing) groups and the deep knowledge of relevant details. Even if all this is readily available, institutions might not be transferable “off the shelf” because of social, cultural, or environmental differences among groups (Aoki, 2001; Powers et al., 2016; Singh et al., 2017).

An alternative view is that evolution of institutions is a result of within-group design processes driven by the motivation of the whole group or some of its subgroups to increase their material well-being or some more general utility. For example, Ostrom (1990) outlines a number of “design principles” for stable and successful management of common resources by local communities. Early 18th-century pirates created democratic institutions (with separation of power, checks and balances, and written constitutions) which helped to make pirate predatory groups very efficient (Defoe, 1972/1724; Leeson, 2009). Similar examples exist among contemporary prison gangs (Skarbek, 2012). Singh et al. (2017) forcefully argue for the importance of self-interested design in the creation of institutions. They also put forward a *self-interested enforcement* hypothesis, according to which many group-level traits and institutions can be explained by the differences in relative enforcement capabilities of different group segments. We note that the idea of self-interested design also captures key aspects of human social life—that we can in fact make guesses about the future and the future behavior of our peers. One can view the strategy update method foresight as an example of self-interested design.

One goal of the work outlined next was to extend our approach to the case of collective actions under institutionalized punishment in small-scale societies. Specifically, our assumption was that the division of labor between leaders who punish cheaters and the rest of the group who produce collective goods is already established and collectively endorsed (Garfield et al., 2019, Wiessner, 2019). We wanted to see how it would evolve in small-scale societies. (Note that Isakov and Rand [2012] and Roithmayr et al. [2015] studied institutionalized punishment in more modern states.) Our second goal was to compare selective imitation and foresight with respect to their ability to identify and converge to cooperative social institutions.

We studied the evolution of institutionalized punishment using two models. In the first model (Perry & Gavrilets, 2020), each group consists of just two players: a subordinate who is charged with producing a collective good and a leader whose responsibility is to monitor the effort of the subordinate and punish them if they shirk. The simplicity of this model allowed for substantial analytical progress in understanding its behavior. In the second, more general model (Gavrilets & Duval Shrestha, 2020), each group has n subordinates producing a collective good and a single leader monitoring their effort. In spite of the complexity of this model, some analytical progress was also possible. We also used agent-based simulation to advance our understanding of both models.

1. *Two-player leader-subordinate game*. In Perry and Gavrilets (2020), we consider a simple 2 x 2 game between a leader and a subordinate, which is based on the inspection game (Fudenberg & Tirole, 1992). The subordinate is tasked with producing a benefit at a personal cost to themselves, while the leader has a vested interest in seeing that the good is produced.

The subordinate can either produce the good ($x = 1$) or shirk on the production of the good ($x = 0$). If the subordinate produces the good, they pay a cost of c to produce a good of value b. The leader receives share $0 \leq \theta \leq 1$ of the good produced as tax, while the subordinate keeps the remaining share $1 - \theta$. The leader can either enforce production via inspection ($y = 1$) or not ($y = 0$). Inspection costs the leader h, but in the event that a leader inspects a non-producing subordinate, they inflict a punishment of d at a cost of h. We assume that all parameters are positive. Table 6.1 describes the corresponding payoff matrix.

Since we are interested in drawing parallels with the first- and second-order free-rider problems in collective action, we make assumptions in such

TABLE 6.1: **Payoff matrix for the leader–subordinate game**

	Leader		
Subordinate		**Inspect**	**Don't Inspect**
	Produce	$(1-\theta)b-c, \theta b-h$	$(1-\theta)b-c, \theta b$
	Shirk	$-d, -h-k$	0, 0

a way that the subordinate has no incentive to see the good be produced unless they are facing punishment. First, given that the subordinate contributes (i.e., $x = 1$), the benefit to the leader exceeds its cost of inspection (i.e., $\theta b > h$). Second, we assume that without punishment (i.e., if $y = 0$) the subordinate is not motivated to contribute, but facing the threat of punishment (i.e., if $y = 1$), the subordinate, however, is motivated to contribute: $-d \leq (1-\theta)b - c \leq 0$.

In this game, the only Nash equilibrium is the one where the subordinate does not produce and the leader does not inspect. We then extended this model by considering mixed Nash equilibria, level-k cognition (which captures some aspects of the theory of mind), and two methods of learning: reinforcement learning (Borgers & Sarin, 1997) and payoff-biased selective imitation (Hofbauer & Sigmund, 1998). In the former case, after each round, the probability of playing a particular strategy is increased by a value proportional to the payoff received. In the latter case, individuals compare their payoff with that of a peer and choose to either copy the selected individual (if their payoff is higher than the focal individual's) or keep their own strategy. In all these extensions, the state of nothing being done remains the only equilibrium.

We then introduced foresight into the model. While allowing that foresight for the subordinate did not result in any differences, the introduction of foresight for the leader allows for the emergence of a new Nash equilibrium ($x = 1$, $y = 1$) where the leader always inspects and the subordinate always produces. This equilibrium appears if the weight of the future payoff is sufficiently large:

$$\omega > h/(\theta b + h)$$

Under this condition, the cost of inspection for the leader $(1-\omega)h$ is overcompensated by the future benefit $\omega\theta b$ coming from the subordinate's production effort in the next round.

We also showed the same Nash equilibrium (1, 1) appears if, instead of relying on foresight, leaders copy the action of other leaders who have higher payoffs. That is, both foresight and selective payoff–biased imitation result in leaders enforcing commoners' production.

2. *Collective action problems with institutionalized punishment*. In a follow-up paper (Gavrilets & Duval Shretha, 2021) each group has not just one but an arbitrary number of subordinates. However, our main results were similar: Foresight increases leaders' willingness to punish free-riders, which in turn leads to a boost in cooperation. Overall this leads to the emergence of an effective institution for collective action as measured by increased production and monitoring. We also observed that largely similar outcomes can be achieved by selective imitation when leaders copy other, more successful leaders. Foresight and selective imitation can interact synergistically, leading to a faster convergence to an equilibrium. What seems to happen is that foresight design leads to a faster establishment of a social innovation in a single group, while selective imitation speeds up its spread across other groups. One difference with the earlier two-player model was that while in the simpler model the equilibria under foresight and selective imitation were exactly the same, this was not the case anymore in the model with multiple subordinates.

I want to stress that although both selective imitation and foresight can result in similar outcomes, their prerequisites differ. Selective imitation is a cognitively simple optimization method based on learning from others with whom the focal agent (i.e., an individual or a group) shares important characteristics (so that the strategy used by the "model" remains feasible and successful for the "mimic"). The agent using selective imitation aims to be as successful as its model. Foresight and, more generally, self-interested design also use social information and learning about the behavior of others. However, they are not restricted to interactions with similar agents, and agents using them can become more successful than their social partners. Cognitive skills needed for foresight, as modeled here, are not too demanding. Predicting others' behavior requires some theory of mind, which can be formed on the basis of previous observations or just by asking a question: What would I do if I were in their place? With respect to group traits (such as social institutions), foresight could work within a single group. In contrast, selective imitation requires multiple groups, the transfer of relevant information between them, and (cultural) group selection.

In our simulations, we assumed the same rates of strategy revision for both mechanisms. However, imitation of institutions from other groups is likely to be a rarer event than attempts to improve poorly functioning institutions by local "means." This implies that the relative rate of social evolution by cultural group selection will likely be slower than that by self-interested design. If, however, selective imitation is unconstrained, the timing of adoption of a new effective institution by different groups will be more similar than that under self-interested design because it will spread in an infection-like fashion.

Overall, these results support the power of foresight in promoting cooperation. We have shown that foresight makes monitoring and punishment a utility-increasing option (Perry et al., 2018). This, in turn, leads to increased production and cooperation and the emergence of an effective institution for collective action by self-interested design (Singh et al., 2017). Richerson et al. (2016) questioned the existence of "the alternatives to [cultural group selection that] can easily account for the institutionalized cooperation that characterizes human societies" (p. 16). These results offer one such alternative.

3. *Dynamics of injunctive social norms in heterogeneous groups*. Here, following Gavrilets (2020), I illustrate how the idea of foresight can be applied to model the decision-making of individuals influenced by injunctive social norms.

Consider a very common situation: You need to cross the street, there are no cars or police around, but the crosswalk sign says "don't walk", and there are several people waiting for it to change. You know that you are supposed to wait. You also expect that if you break the norm and cross the street, the other people will likely disapprove of you. But you are in a rush. What do you do?

To approach this question theoretically, consider a focal individual who can either follow the (injunctive) norm and wait for the traffic light to turn green ($x = 1$) or jaywalk ($x = 0$). Let b be the expected net material benefit of crossing the street rather than waiting. (Parameter b can also account for the cost of being observed by the police or being hit by a car when jaywalking.) Let v be an intrinsic value of following the norm (which can be viewed as the strength of norm internalization). We posit that an individual violating the norm assumes that others who do follow it disapprove of their behavior if they observe it (Fehr & Schurtenberger, 2018).

Let p be the focal individual's estimate of the frequency of such people (e.g., based on previous observations). Let κp be the expected normative cost of their disapproval, where κ is the maximum normative cost of passive disapproval by others for the focal individual. Then the utility of action x, where x can equal 0 or 1, can be written as

$$u = vx + b(1 - x)$$

Acting according to the norm will result in approval by other followers, the value of which is $v_a p$, while violating it will cause disapproval, the value of which is $-\kappa p$, where v_a is the maximum normative value of approval. Therefore, an individual equipped with foresight can infer that their current action x will also have a future consequence captured by the utility function

$$u' = v_a px - \kappa p(1 - x)$$

Following our approach, we can combine the two utility functions into one:

$$U = (1-\omega)u + \omega u' = [(1-\omega)v + \omega v_a p]\,x + [(1-\omega)b - \omega\kappa p](1-x)$$

We thus predict that the individual will comply with the norm (i.e., choose $x = 1$) if the expression in the first pairs of parentheses is larger than that in the second pair of parentheses, that is, if

$$(1-\omega)v + \omega(v_a + \kappa)p > (1-\omega)b$$

If $\omega = 1/2$, the above equation simplifies to $v + (v_a + \kappa)p > b$. That is, the sum of the intrinsic value of following the norm and normative benefits of approval and costs of disapproval by others has to be larger than the material benefit of violating the norm.

Note that an individual with a low normative value v relative to the potential material benefit b will still comply with the norm if the expected normative cost of disapproval κp and/or approval $v_a p$ by others is high enough. Both these terms increase with the estimated frequency p of people following the norm.

In the first three models, foresight motivates individuals to engage in costly punishment. In the last model, it provides a motivation to follow a social norm to avoid punishment. I will now, in the final example, show that individuals with foresight can also engage in costly acts of manipulation or deception to obtain future benefits from their group-mates.

4. *Tactical deception*. McNally and Jackson (2013) introduced the following model (see also Szolnokii & Perc, 2014). There is a population of individuals engaged in dyadic games of the prisoner's dilemma type. In any given interaction, individuals can choose to cooperate by providing a fixed benefit b to their partner at a fixed cost c to themselves ($b > c$) or to defect and pay no costs. There are three possible strategies: conditional cooperator (CC), tactical deceiver (TD), and honest defector (HD). CCs intend to cooperate only with other cooperative individuals and to not cooperate with defectors. HDs always defect. TDs always defect as well but attempt to deceive the partner by pretending they will cooperate. The act of deceiving has cost d but can fool CCs with probability q, who may then provide a benefit b. It is assumed that the cost of deception is smaller than the cost of cooperation ($d < c$).

In this model, if q decreases with the frequency of TDs (which can happen if CC individuals learn to recognize TDs better as they become more common), there is a polymorphic equilibrium where CCs and TDs coexist at equilibrium, while HDs are absent. McNally and Jackson (2013) did not discuss foresight, but their model essentially postulates it. Indeed, in their model, tactical deceivers effectively trade the immediate cost d of a deceiving act for the future benefit bq to be received from a deceived conditional cooperator. McNally and Jackson (2013) argue that the benefit of eliciting cooperation at lower cost may help select for tactical deception in species with more frequent and diverse forms of cooperation. Obviously, deception can have other benefits in humans and animals besides in the context of cooperation, for example, in mating behavior and aggressive interactions (Hall & Brosnan, 2016; McNally & Jackson 2013; Mokkonen & Lindstedt, 2016).

IV. IMPLICATIONS

The basic idea of foresight is simple: Pay certain costs (or forfeit getting certain benefits) now to get more benefits (or avoid paying larger costs) in the future.

Empirical facts on which the strategy update method foresight is based are well established in psychology. As argued, foresight can be important in punishment, cooperation, learning, cumulative culture, social norms, and social institutions. Having these ideas captured in mathematical models allows one to use a diverse set of theoretical tools from game theory and evolutionary biology to further advance studies of human decision-making and the processes of social and cultural evolution. One can also bring mathematical modeling into the studies of prospection, mental time traveling, and intertemporal choices, which are becoming increasingly important in psychology (Berns et al., 2007; Frederick et al., 2002; Szpunar et al., 2014). Next, I highlight three additional general implications of our results.

A. Game Theory and Human Rationality

Classical game theory assumes, usually implicitly but often explicitly, that players have complete and common knowledge of the structure of the game and that they have the ability to go through all necessary calculations to identify the corresponding Nash equilibria in pure or mixed strategies. On the other hand, evolutionary game theory typically assumes, by analogy with population genetic processes in evolutionary biology, a complete absence of rationality and free will or awards rather limited cognitive abilities to players (who use myopic best response or selective payoff–biased imitation). There have been only limited attempts to bridge the huge theoretical gap between these two extremes. These earlier attempts include various level-k models (Nagel, 1995; Stahl & Wilson, 1995) as well as models where players are able to predict when the dyadic interactions they are engaged in will end (Heller, 2015; Jehiel, 1995, 1998, 2001). This earlier work as well as our results on foresight point to the importance of extending the toolkit of game theory by adding more realism to assumptions about cognition and decision-making.

The earlier work in evolutionary game theory validated the importance of Nash equilibria in many models by demonstrating that individual players or populations of players with rather limited cognitive abilities (implied by myopic best response or selective imitation strategy update protocols) can nevertheless incrementally converge to the corresponding Nash equilibria (Hofbauer & Sigmund 1998; Sandholm, 2010). Foresight as modeled here may provide a way to access a wider or a more profitable array of Nash equilibria, further bridging the classical and evolutionary approaches in game theory.

B. Cooperation

Although potentially very profitable, cooperation is difficult to establish and maintain, especially if multiple players are involved. Intensive research over the last half a century by evolutionary biologists and social scientists has uncovered multiple mechanisms that promote cooperation. These include kin selection, direct and indirect reciprocity, selective incentives (i.e., reward and punishment), group selection, within-group heterogeneity, leadership, social norms, and institutions. Some of these mechanisms emerge naturally as a result of particular biological or social processes (e.g., kin selection, reputation, or group selection), while the appearance of others (e.g., punishment, social norms, and institutions) requires an additional level of explanation to avoid second-order free-rider problems. Most of the theoretical work done in this field has assumed very limited cognitive abilities of players. The models of foresight show that allowing for moderate cognitive abilities can greatly simplify the conditions for the emergence of punishment, leadership, and social institutions, which in turn make cooperation easier. In particular, foresight can motivate individuals to punish free-riders or norm violators, and simultaneously it can motivate cooperation or norm following. Foresight can also motivate leaders to ignore the immediate costs of monitoring, coordination, and norm promotion in order to enjoy future benefits of cooperation.

C. Selective Imitation, Cultural Group Selection, and Designs

Ideas, methods, and models of cultural evolution theory are currently moving to the forefront of many social sciences including anthropology, economics, psychology, and political sciences (Bowles, 2016; Gintis, 2016; Henrich, 2016; Petersen, 2016; Petersen & Aarøe, 2015; Turchin, 2016). A particularly powerful force of cultural evolution is selective payoff–biased imitation, which can work at both the individual and group levels. Human capacity for cultural learning and selective imitation has no doubt greatly contributed both to our uniqueness as a species (Boyd et al., 2011; Henrich, 2016) and to the cooperative social institutions we have built (Richerson et al., 2016). However as with almost any other evolutionary force, selective imitation is most efficient under some conditions but can fail under others. The foresight models discussed draw attention to an alternative mechanism—self-interested design—which can work in tandem with selective imitation or in situations where selective imitation is not effective. These models also show that development of group-level adaptations benefiting some subgroups or the whole group does not require between-group selection or competition. Selection is still crucial though, but it happens at the level of mental processes and scenario-building.

V. EXTENSIONS

There are several important directions this approach can be extended to.

A. Other Game-Theoretic Models

Our results indicate that foresight can affect the basic dynamics of a game by altering the structure of Nash equilibria. So far we have looked at public goods games and the leadership game. It would be a worthwhile exercise to study the effects of one-step foresight in a wider range of classical games such as the prisoner's dilemma and related 2 × 2 games, various coordination games, rock–scissors–paper, and versions of the volunteer's dilemma. It would also be interesting to contrast foresight with other strategy revision protocols as well as with various conditional strategies, such as those that are extortion-like (Press & Dyson, 2012; Stewart & Plotkin, 2013). In simple cases, one can expect to obtain some analytical results.

We have studied only one-step foresight, generalizing myopic optimization. However, individuals may be using higher-order theories of mind and care about longer-term payoffs (de Weerd & Verbrugge, 2011; de Weerd et al., 2013, 2014, 2015). Models capturing these features would be much more complex and require numerical investigation but would be potentially more realistic. It would be important to combine Bayesian inference about peers' strategies into foresight framework (see Khalvati, Mirbagheri, et al., 2019; Khalvati, Park, et al., 2019). Moreover, rather than predicting individual behavior, agents can evaluate common knowledge in their group and then attempt to predict the group's intention and sentiments (Shteynberg, 2015, 2018). A consensus of what a particular person might do in a particular situation would make punishment more acceptable to the other group members.

B. Foresight in Leadership

There are a number of important directions for extending our work, such as explicitly considering the dynamics of population densities (as in Powers & Lehmann, 2013, 2014), allowing for the simultaneous presence of competition of egalitarian and hierarchical groups (as in Hooper et al., 2010; Powers

& Lehmann, 2013, 2014), and allowing for changeable rather than fixed taxes as well as for a market for leaders (as in Hooper et al., 2010). Also, so far we have only modeled leaders as punishers. One can use a similar approach where leaders' effort is directed toward coordination or norm promotion. One can also conceptualize laws as punishers and model their effects on individual and group behaviors.

C. Evolution of Foresight

In our work, we have taken for granted that foresight is already present and sought only to show how it could be an effective route to overcoming the first- and second-order free-rider problem. An important evolutionary question is under what conditions foresight would evolve in a population where it is initially absent. As argued elsewhere (Alexander 1987, 1989, 1990), costly foresight could evolve if it increases biological fitness. Evolution of foresight can be driven by selection for increased individual reproductive success under the action of asocial or social factors. In the latter case, it could be selection arising from competitive interactions (e.g., as implied in Machiavellian intelligence hypothesis [Byrne & Whiten, 1988; Gavrilets & Vose, 2006; Whiten & Byrne, 1997), or selection can be due to potential benefits of cooperation (Dunbar, 1998, 2003, 2009; Gavrilets, 2015b) that can be achieved by individuals having the theory of mind. Potential benefits of cooperation can be augmented by group selection. All these ideas are worth exploring theoretically.

D. Model Validation

As I have argued, the facts that both humans and non-human animals care about the future and are able to predict to a certain extent the behavior of their group-mates are undeniable. The models outlined in this chapter aim to capture these facts in simple mathematical terms in order to predict the dynamics of cooperation and punishment in groups. Whether these simple models are adequate for describing real-world phenomena is an open empirical question. As with other game-theoretical approaches, validating the models can be done at different levels. One is a level of individual decision-making. Another is a level of group behavior. My hope is that existing methods of experimental economic games, surveys, and observational approaches can be appropriately adapted for studying foresight.

VI. CONCLUSION

Classical game theory assumes complete rationality and availability of all relevant information to the players. On the other hand, evolutionary game theory usually makes minimalistic assumptions about human (and animal) decision-making processes. Both these theories have been useful in establishing foundations of a general theory of social behavior. Starting with this foundation, we can now move toward more realism in our models by capturing in them not only the "shadow of the future" but also the theory of mind. Such a step allows us to take a new look at old problems but also to uncover new challenges in understanding social and cultural evolution and their theoretical and practical solutions.

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